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RESEARCH REPORT BL-R-931-5G-7

OXIDE CATHODE AND PRIMARY GRID EMISSION STUDIES

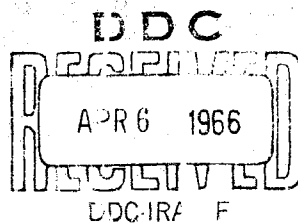### CONTRACT NO. W-36-039-sc-33643

MONTHLY REPORT NO. 7

November 1947

U. S. Army
Signal Corps Engineering Laboratories
Belmar, New Jersey

J. W. McNall
H. F. Ivey

December 8, 1947

WESTINGHOUSE ELECTRIC CORPORATION

Lamp Division   Bloomfield, N. J.

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RESEARCH REPORT BL-R-931-5G-7

OXIDE CATHODE AND PRIMARY GRID EMISSION STUDIES

ABSTRACT

Methods have been developed for making relative gas pressure measurements in 715 A/B tubes. The electrostatic fields at the cathode of these tubes have also been investigated. Both these points are of interest concerning the electrical breakdown of these tubes under high voltage pulsed operation. Preliminary investigations seem to indicate that breakdown occurs during the pulse, when the applied voltage is lowest. Additional improvements have also been made in the test equipment.

The search for a suitable anode material for the special tube for x-ray analysis of the material evaporated from an oxide cathode has been continued, but the problem is not yet solved.

Thermionic emission measurements have been made on "Svea" metal both before and after contamination by an oxide cathode. Before contamination the emission was much greater than that reported for clean pure iron and could not be reduced to any great extent by heat treatment. Extraordinarily large "A" values were obtained. "Svea" metal can be activated by exposure to an oxide cathode, but the rate of activation seems considerably less than that for tungsten.

PLANS FOR FUTURE WORK

The investigation of breakdown in tubes with oxide cathodes operating under pulsed high voltage conditions will be continued. Photographs of synchroscope traces will be taken to determine in what part of the cycle breakdown occurs.

As soon as a suitable anode material is found, the experiments on x-ray analysis of the material evaporated from an oxide cathode will be continued.

The thermionic emission of "Svea" metal and of other materials, both when clean and when contaminated by an oxide cathode, will be investigated.

PERSONNEL

Dr. J. W. McNall
Dr. H. F. Ivey   (full time)
Mr. R. S. Sheetz   (full time)
Dr. C. K. Lui

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1. INTRODUCTION AND PERSONNEL

Work was directed during the month of November toward all three of the major phases of the program, with particular emphasis on the electrical breakdown of tubes containing oxide cathodes and the primary emission of "Svea" metal. Mr. Zinn of E.S.L. spent a day here at our laboratory. He requested that each monthly report contain a statement of the engineering man-hours devoted to the project during that month.

For the first six months of the present contract 1506 hours of engineering time and 244 hours of non-engineering time were expended on this project. During November (which had only nineteen working days) 340 engineering hours and 39 non-engineering hours were expended, raising the totals to 1846 and 283, respectively. The amount of engineering time for this past month corresponds to 2-1/4 man-months.

2. INVESTIGATION OF THE BREAKDOWN OF OXIDE CATHODE, HIGH VOLTAGE, PULSED VACUUM TUBES

Gas Pressure Measurements

One of the possible factors influencing tube breakdown is the gas pressure within the tube. It was therefore felt that an apparatus should be developed which would enable relative pressure measurements to be made.

The circuit used is based on the ionization gauge principle using the screen grid of the tetrode as the electron collector and the plate as the positive ion collector. In order to move nearly simulate actual operational conditions the filament is heated to its normal operating temperature during pressure measurements, and it is therefore necessary to use the control grid to limit the electron flow. Unless this is done excessive heating of the elements results.

Difficulty was encountered on using an AC filament supply. Under this condition an electron flow to the negative plate was observed. This was attributed to electron emission from the heater, parts of which were being driven negative with respect to the plate during a portion of the AC cycle. To remedy this situation a DC filament supply was used with the negative side connected to the cathode.

Curves of positive ion current vs electron current were obtained for one tube and are included in this report (Fig. 1). From these curves it was deemed advisable to take pressure measurements at an electron current of three milliamps, since at higher currents the curve starts to bend slightly.

It should be noted that the pressure readings obtained are not in terms of pressure units but are in terms of micro-amperes and can therefore be used only as a means of comparison between various 715 A/B and 5D21 tubes.

Improvement of Pulse Shapes

In order to obtain true pictures of current and voltage conditions
in the grid circuit it was necessary to alter the circuit slightly. Most
of the trouble encountered was due to stray capacity. To improve the wave
shapes the following changes were made:

1. The capacitance of the capacity divider used for observing grid
   voltage was reduced by a factor of five.

2. Three of the four sockets in the test set were disconnected since
   only one tube is being tested at a time, thus eliminating stray
   capacitances in this part of the circuit.

These changes resulted in a considerable reduction of circuit
capacitive coupling, as evidenced by viewing the wave shapes without the
tube in the socket. The limiting factor with respect to improving the
wave shape is the interelectrode capacity of the tube. No attempt was
made to remedy this situation, however, since this condition is present
in regular tube operation.

Calibration

Calibrations of grid current, grid voltage, screen grid current,
and load current have been made. Means of obtaining quantitative measure-
ments of plate voltage will be added.

High Voltage Pulsed Test of 715B Type Tube

Curves of screen grid current, grid current, and plate current
vs screen grid voltage have been obtained for various cathode temperatures.
These curves indicate that the tube is space charge limited for heater
voltages of approximately 25 volts and above and emission limited for
voltages of about 20 volts and below. This had to be determined in order
to investigate the effect on electrical breakdown of electrostatic fields
at the cathode.

Several photographs have been taken of the synchroscope trace
for the voltage across the load resistance during arcing conditions.
Although these give indications that the arc is initiated during the
pulse (the time at which the voltage across the tube is a minimum) the
proof is not definite. The photographs show a trace leading from the
vicinity of the pulse, but due to the narrow pulse width it is not pos-
sible to say whether the arcing is started during or a few microseconds
before or after the pulse.

These indications are based on only a small amount of evidence.
By continuing this photographic investigation of the occurence of electrical
breakdown, it is hoped that the causes can be determined and subsequently
eliminated.

3. ANALYSIS OF THE MATERIAL EVAPORATED FROM
AN OXIDE CATHODE

Progress on this phase of the program has been delayed because of the lack of a suitable material for the anode of the special tubes involved. It was previously reported that the molybdenum sheet originally used for this purpose gave a diffraction line with the same d/n value as that of the line used for detection of barium, presumably due to some contamination or oxide of the molybdenum. The molybdenum samples from Westinghouse Division No. 313 referred to in Monthly Report No. 6 have not yet been received for analysis because of equipment difficulties in that division. An order has been placed for molybdenum sheet from an outside supplier (Fansteel) in the hope that a sample free of the interfering line can be found and the experiments continued.

X-ray diffraction patterns have been made for samples of Ta, Cb, Swedish Iron, and Pt. The Ta and Cb lines do not interfere with the Ba or BaO identification but there are no lines suitable for "calibration" purposes. Both the Swedish Iron and the platinum patterns have a good line for calibration but it is hoped that iron (or nickel) can be avoided because of the difficulty of outgassing. In the case of Pt there is a line (d/n = 0.978) which is very close to the BaO line (d/n = 0.975). Dr. Lui is making exposures of Pt and BaO on the same film to see if the difference can be detected.

One possible way of removing the conflict between the Ba line and the unidentified line from the Mo would be to choose another Ba line of different d/n value. Unfortunately, the Ba line of next larger d/n value (1.022) coincides with a nickel line and hence is not useable since it is very likely that nickel will be evaporated from the oxide cathode base. The Ba line of next smaller d/n value (0.915) is so far in towards the center of the film that the sample-to-film distance would have to be greatly increased to get the line on the film and the exposure time would be unreasonable.

In a paper by Benjamin and Jenkins[1] there are data which indicate that it is very unlikely that the contamination of our molybdenum is really barium. By means of electron projection studies of field emission these workers found that migration of Ba on Mo begins at temperatures as low as $600^\circ K$ and is complete at $800^\circ K$. Evaporation of Ba from Mo was found to begin at $900^\circ K$ and was complete at $1400^\circ K$. It will be recalled that in our case heating to $1490^\circ C$ brightness temperature (true temperature $1930^\circ K$) for three minutes in vacuum failed to remove the line in question from the diffraction pattern.

4. PRIMARY EMISSION FROM "SVEA" METAL CONTAMINATED
BY AN OXIDE CATHODE

Following evacuation of the thermionic emission tube containing a filament of "Svea" Metal (a high-purity iron) described in Monthly Report No. 6, emission measurements were made. The first of these indicated an

emission larger by more than five orders of magnitude than that reported by Wahlin[2]. The corresponding thermionic constants were $\phi = 5.27$ e.V. and $A = 2.5 \times 10^9$ amp/cm^{2}deg^2 as compared to Wahlin's values of $\phi = 4.21$ e.V., $A = 1.5$ amp/cm^{2}deg^2 for α-Fe and $\phi = 4.48$ e.V., $A = 26$ amp/cm^{2}deg^2 for B-Fe. It was concluded that this large emission was due to contamination of the filament during breakdown of the oxide-coated filaments. However it is not easy to explain the fantastically high A value obtained.

Heating the filament at the highest temperature that was considered safe (1360°K) did not reduce the emission. After the failure of these attempts it was decided to expose the filament to the oxide cathodes for additional contamination. These experiments seemed to indicate that although the iron can be activated, the rate at which this activation occurs is considerably less than that for tungsten. The exposure was continued until one of the oxide-coated filaments burned out. At this point the emission was almost five orders of magnitude greater than the original value and still increasing. The thermionic constants were $\phi = 2.60$ e.V. and $A = 660$ amp/cm^{2}deg^2. At $T = 1100$°K the emission was still one-twentieth that of contaminated tungsten at its maximum activity and the same temperature.

The iron filament was now decontaminated by heating and the emission was gradually reduced to within a factor of ten of the original value. At this point the "decontaminating temperature" was increased to 1390°K, at which temperature the life of the filament was only four and a quarter hours. During this period the emission decreased until ϕ reached 4.29 e.V. and $A = 7800$ amp/cm^{2}deg^2. This value of ϕ is the same as Wahlin's, but the A value if 5000 times higher. It is of interest to point out that the average of six photoelectric determinations of the work function of iron made in the period from 1928 to the present gives $4.71 \pm .07$ e.V., which is half a volt above Wahlin's (the only recent) thermionic determination.

Iron has a crystallographic transformation from the α(body-centered cubic) form to the γ(face-centered cubic) form at 1179°K (860°C brightness). A typical Richardson plot for the "Svea" metal filament is shown in Fig. 2 for both increasing and decreasing temperatures. It is seen that the two crystal structures give different Richardson plots and that there is a "hysteresis" effect in the neighborhood of the transition point. At the transition point, at least for increasing temperatures, the emission is usually very erratic and unsteady for a period before settling down to a steady value. It is hoped to make electron projection studies of this phenomenon in the near future. Because of this change in crystal structure the iron filament becomes badly distorted after several passages through the transition point, although no evidence of crystal offsetting was seen under the microscope after the filament was removed from the tube.

The tube was cut open and new filaments installed. This time the "Svea" metal was exposed to air after installation for only a few hours. Also the new oxide-coated filaments installed were coated to within 1/4" of the ends. In the previous cases burnout of these filaments occurred

at the uncoated nickel end sections, which operate at a higher temperature than the coated center section because of t.. lower emissivity of nickel compared to the oxide. It is hoped to avoid this difficulty by using the longer coated length. It is not desirable to coat the filament all the way to the end since some unconverted carbonate might remain and constitute a source of gas during operation of the tube.
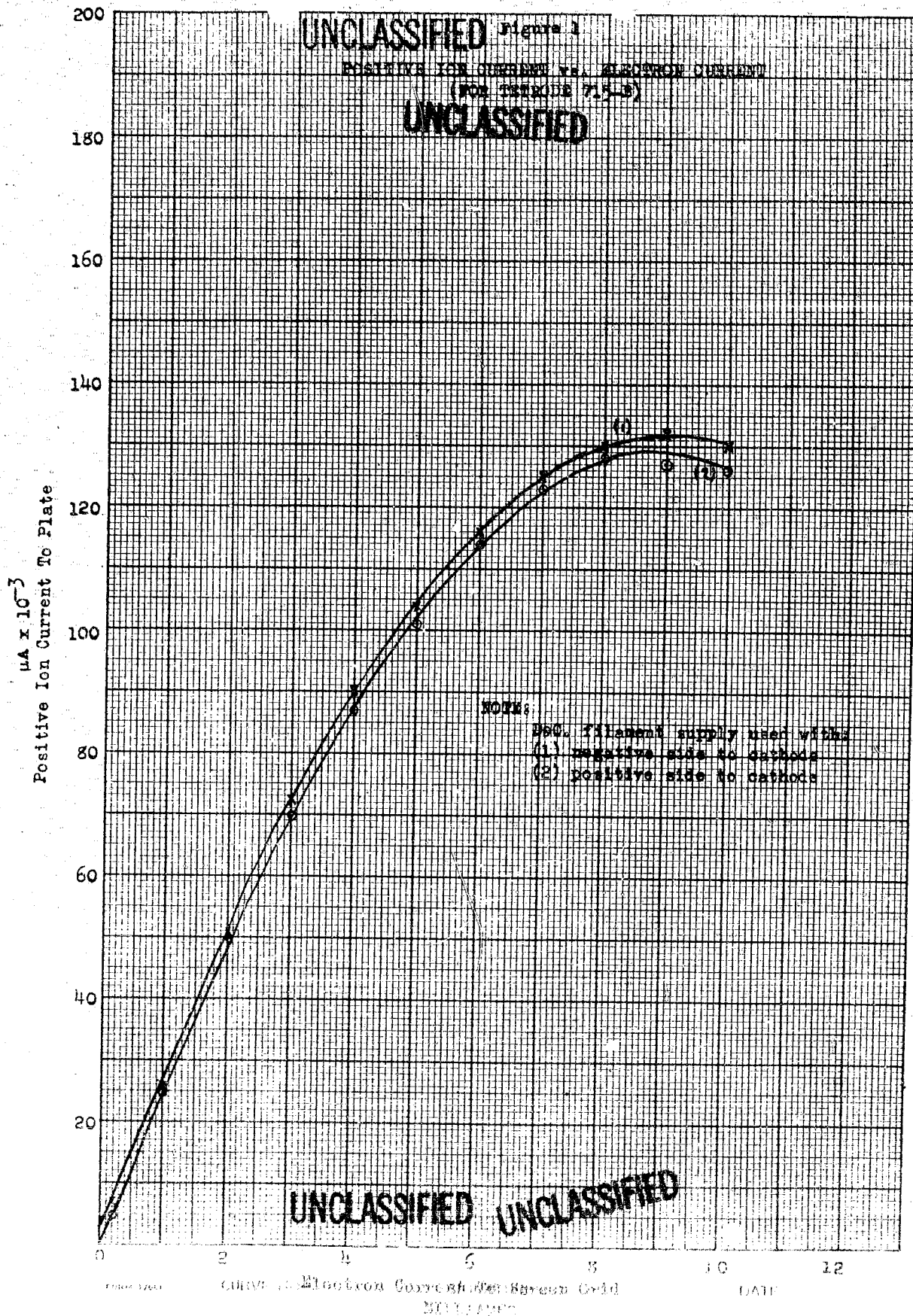
For this second iron filament, emission measurements were made while the tube was still on the vacuum system and before the oxide-coated filaments had been heated (except for the bake). Despite this precaution against contamination, the emission was almost as high as it was for the first filament which had been exposed to the oxide cathodes during the carbonate conversion, indicating that the assumption that the disagreement with Wahlin's data was due to preliminary contamination during cathode breakdown was false. The emission also showed a tendency to increase with time. The oxide cathodes were then converted, the other tube parts out-gassed, and the tube sealed off. Measurements on this filament will be continued.
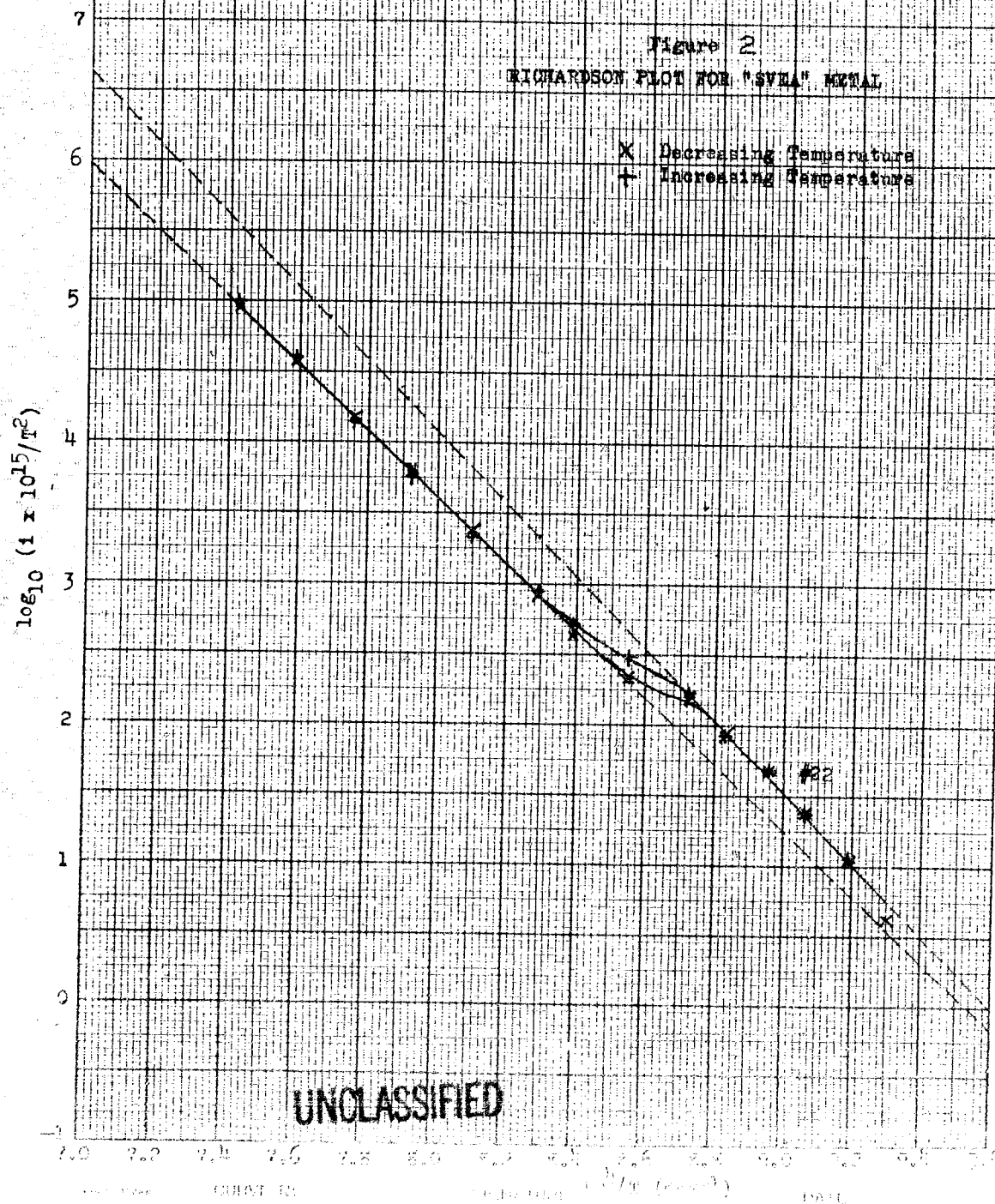
ERRATUM

In Monthly Report No. 6, p. 2, the fourth line from the bottom of the page, substitute "unidentified" for "identified".

REFERENCES

1. M. Benjamin and R. O. Jenkins, Proc. Roy. Soc., London, A180; 225 (1942).

2. H. B. Wahlin, Phys. Rev., 61; 509 (1942).

UNCLASSIFIED Figure 1

POSITIVE ION CURRENT vs. ELECTRON CURRENT
(FOR TETRODE 7.5-B)

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NOTE:

D.C. filament supply used with:
(1) negative side to cathode
(2) positive side to cathode

Figure 2
RICHARDSON PLOT FOR "SVEA" METAL

X Decreasing Temperature
+ Increasing Temperature

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